1 DRAFT
2 ENHANCED BIOREMEDIATION FIELD TEST REPORT
3 OPERABLE UNIT 2
4 SITE ST012 – LIQUID FUELS STORAGE AREA
5 FORMER WILLIAMS AIR FORCE BASE
6 MESA, ARIZONA
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27 30 November 2015
28
29 Contract Number: FA8903-09-D-8572 - 0002
30 Project No. 9101110001
31 CDRL No. A001

32 SIGNATURE PAGE

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FORMER WILLIAMS AIR FORCE BASE
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121 LIST OF ACRONYMS AND ABBREVIATIONS

%	percent
AFB	Air Force Base
AFCEC	Air Force Civil Engineer Center
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
CZ	Cobble Zone
DNF	denitrifying bacteria
EBR	enhanced bioremediation
frac tank	fractionation tank
ft msl	feet above mean sea level
GEO	geobacter
gpm	gallons per minute
JP-4	jet propulsion fuel grade 4
LNAPL	light non-aqueous phased liquid
LSZ	Lower Saturated Zone
mg/l	milligram per liter
MGN	methanogenic bacteria
Microbial Insights	Microbial Insights, Inc.
OU-2	Operable Unit 2
qPCR	quantitative polymerase chain reaction
PLFA	phospholipid fatty acid
RD/RAWP	Remedial Design/Remedial Action Work Plan
RODA-2	Record of Decision Amendment 2
SEE	Steam Enhanced Extraction
SRB	sulfate reducing bacteria
ST012	Site ST012 Liquid Fuel Storage Area
TEA	terminal electron acceptor
TestAmerica	TestAmerica Laboratories, Inc.
TPH	total petroleum hydrocarbons
TTZs	Thermal Treatment Zones
UWBZ	Upper Water Bearing Zone
µg/l	microgram per liter
VOC	volatile organic compound

122

123 **1.0   INTRODUCTION**

124   Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) prepared this
125   Enhanced Bioremediation (EBR) Field Test Report for the Air Force Civil Engineer Center
126   (AFCEC) to provide details related to EBR field activities conducted for Operable Unit 2 (OU-2)
127   at the former Williams Air Force Base (AFB) in Mesa, Arizona (Figure 1-1). OU-2 is composed of
128   the Installation Restoration Program Site ST012, the former Liquid Fuels Storage Area (ST012)
129   (Figure 1-2), where historic releases of jet propulsion fuel grade 4 (JP-4) and/or aviation gasoline
130   have resulted in contaminated soil and groundwater.
131
132   An OU-2 Record of Decision Amendment 2 (RODA 2) (AFCEC, 2013) revised the groundwater
133   remedy to implement steam enhanced extraction (SEE) followed by EBR. The purpose of the
134   EBR Field Test was to obtain data to support EBR design.

135   **1.1   Purpose and Organization of Report**

136   The purpose of this EBR Field Test Completion Report is to document the field activities and
137   associated results related to the EBR Field Test Plan (AMEC, 2014b), including interpretation of
138   results.
139
140   This report consists of five sections, plus appendices. Section 1.0 presents an introduction and
141   background information. Section 2.0 describes the field activities including deviations from the
142   Final EBR Field Test Plan (AMEC, 2014b) and laboratory results. Section 3.0 discusses results
143   and estimates parameters for use in EBR design. Appendix A presents low-flow sample collection
144   records. Appendix B includes analytical laboratory results. Data validation narratives are included
145   in Appendix C and microbial results are in Appendix D. Appendix E presents calculations for the
146   estimate of microbial degradation kinetics.

147   **1.2   Background**

148   As part of the ST012 Remedial Design and Remedial Action Work Plan (RD/RAWP) (AMEC,
149   2014a) for implementing the OU-2 RODA 2, the selected remedial action includes an initial period
150   of SEE for mass removal of dissolved contaminants and light non-aqueous phased liquid (LNAPL)
151   within established thermal treatment zones (TTZs), followed by EBR to address LNAPL outside
152   of the TTZs as well as dissolved phase contaminants within and outside the TTZs. Amec Foster
153   Wheeler conducted this EBR Field Test in support of the design for the enhanced bioremediation
154   portion of the approved groundwater remedy for the site. The EBR and SEE modeling report
155   prepared as part of the ST012 RD/RAWP described EBR modeling results using both aerobic
156   and anaerobic processes for remediation. Modeling results for both processes indicated that the
157   remediation goals could be met; however, there were significant assumptions made for the
158   anaerobic approach. Therefore, this EBR Field Test included two single well tracer tests, herein
159   also referred to as push-pull tests, using sulfate as a terminal electron acceptor (TEA) to evaluate
160   appropriate delivery and dosing for EBR at ST012 under the anaerobic scenario. Due to the
161   prevalence of existing aerobic EBR data that can adequately support a future design, this field
162   test only investigated anaerobic EBR to provide data to support evaluation of strategies for

163 aerobic and/or anaerobic EBR and for design of anaerobic methods if this approach is
164 implemented.
165 Monitoring wells ST012-W11 and ST012-W30 were selected for the single-well tracer tests
166 because they are both located outside of the SEE TTZs and both have historical evidence of
167 LNAPL contamination. Both wells are screened in the Lower Saturation Zone (LSZ) and are
168 located on the United States Army Reserve Property to the west of the SEE TTZs (see
169 Figure 1-3). Figure 1-3 also shows the extent of residual LNAPL within each hydrostratigraphic
170 zone as estimated in the RD/RAWP (AMEC, 2014a).

171 **1.3   Field Test Procedure**

172 The EBR field test was conducted as two separate push-pull tests at well locations ST012-W11
173 and ST012-W30. The field test was conducted in general conformance with the EBR Field Test
174 Plan (AMEC, 2014b) which included the following steps:
175
176   1. Baseline Sampling and Well Preparation

177   2. TEA and tracer (solution) mixing and injection

178   3. Monitoring during shut-in period

179   4. Groundwater/solution extraction and sampling during extraction

180   5. Post-extraction sampling

181   6. Review and interpretation of laboratory data

182
183 Each of the above steps is discussed in detail in Sections 2 through 4.

184 2.0   EBR FIELD TEST IMPLEMENTATION

185   The EBR Field Test was conducted in general accordance with the Final EBR Field Test Plan
186   (AMEC, 2014b). This section describes implementation activities.

187 2.1   Site Preparation

188   Coordination with the U.S. Army Reserve Center occurred to gain access to the site for the test
189   and agree on locations for staging of equipment and tanks. Equipment required for
190   implementation was temporarily located within the U.S. Army Reserve Center during the push
191   and pull phases of the EBR test except for the fractionation tank (frac tank) which was used to
192   store extracted groundwater during the pull phase and was located on Avoca Street (which was
193   closed for SEE construction activities).

194 2.2   Baseline Sampling and Well Preparation

195   Prior to initiating the field test, baseline samples were collected. On 16 July 2014, low-flow
196   procedures were followed to collect samples for baseline analysis from monitoring wells
197   ST012-W11 and ST012-W30. Once field readings of temperature, pH, specific conductance,
198   dissolved oxygen, and oxidation-reduction potential stabilized (see Appendix A), samples were
199   collected and submitted to Test America Laboratories (Test America) and Microbial Insights, Inc.
200   (Microbial Insights) for the following analyses:

201   - Chemical Analysis (Test America):
202   - sulfate
203   - bromide
204   - cation/anion balance
205   - Inductively Coupled Plasma Metals
206   - Ion Chromatography
207   - Total Petroleum Hydrocarbons (TPH)
208   - Volatile Organic Compounds (VOCs)

209   - Microbial Population Analysis (Microbial Insights):
210   - quantitative polymerase chain reaction (qPCR) analysis to enumerate the following
211   bacterial groups:
212   - denitrifying bacteria (DNF, nirK and nirS functional genes)
213   - geobacter (GEO)
214   - sulfate reducing bacteria (SRB; APS)
215   - methanogenic bacteria (MGN)
216   - phospholipid fatty acid (PLFA) analysis to quantify total biomass and assess microbial
217   population activity

218
219   On 16 July 2014, attempts were made to use an in-line bio-flo™ filter provided by Microbial
220   Insights to collect samples for microbial population analysis; however, the filters clogged before
221   the required amount of water was collected. Microbial Insights indicated prior to the field test that
222   this is a common occurrence and provided glass bottles to fill with water instead of using the filters

223 if this problem arose. When the samples arrived at Microbial Insights, the laboratory indicated that
224 there was not enough sample to run both sets of tests, so additional samples were collected from
225 each well on 17 July 2014 to conduct the PLFA analysis.
226
227 Prior to beginning the field tests, an oil-water interface probe was used to check for LNAPL in the
228 wells. A trace of LNAPL was detected in ST012-W11 but there was not enough to remove with a
229 bailer. A pressure transducer and AquiStar® TempHion™ Smart Sensor (an in-situ bromide probe
230 and data logger) were then placed inside each well to monitor changes in groundwater elevation
231 and bromide concentrations, respectively, during the testing.

232 2.2.1 Analytical Data from Test America

233 Tables 2-1 and 2-2 present analytical data from Test America for the full suite of analyses
234 performed during baseline, post-shut-in, and post-extraction sampling at ST012-W11 and
235 ST012-W30, respectively. Analytical reports are included in Appendix B and data validation
236 narratives are provided in Appendix C. Sections 2.4 and 2.5 provide additional details on sample
237 collection activities during the post-shut-in and post-extraction periods, respectively.
238

Table 2-1   Analytical Data for ST012-W11

Parameter	Units	Baseline 7/16/2014		Post-Shut-In 9/2/2014		Post-Extraction 9/8/2014	
Sample Location:		**ST012 - W11**					
JP-4 (Total Petroleum Hydrocarbons)							
Diesel Range Organics [C10-C28]	mg/l	0.45	B	0.56		0.095	U
Gasoline Range Organics [C6-C10]	µg/l	3000		2700	Q	73	Q
Total Petroleum Hydrocarbons	*mg/l*	*3.5*		*3.3*		*0.17*	
Volatile Organic Compounds							
1,2-Dichloroethane	µg/l	0.4	U	0.4	UQ	0.4	U
Benzene	µg/l	51		45	Q	0.37	J
Ethylbenzene	µg/l	310		230		2.4	
Methylene Chloride	µg/l	0.8	U	1.1	J	0.8	U
m-Xylene & p-Xylene	µg/l	0.8	U	74	D	2.2	
Naphthalene	µg/l	38	B	43		0.4	
o-Xylene	µg/l	0.4	U	4	U	0.4	U
Toluene	µg/l	0.38	J	1.2	Q	0.4	U
Trichloroethene	µg/l	0.21	J	0.2	UQ	0.2	U
Trichlorofluoromethane	µg/l	0.8	U	0.8	U	0.8	U
Xylenes, Total	µg/l	1.6	U	74	D	2.2	
Total Volatile Organic Compounds	*mg/l*	*0.40*		*0.47*		*0.011*	
Other							
Bromide	mg/l	1.6	J	2.6		2.5	
Sulfate	mg/l	5.4		6.4		280	
Calcium	mg/l	310		300		770	
Chloride	mg/l	800		780		1600	
Iron	mg/l	0.063	J	0.14		0.03	U
Manganese	mg/l	2.2	Q	2	Q	0.067	Q
Magnesium	mg/l	67		67		140	
Sodium	mg/l	79		76		92	
Potassium	mg/l	7.7		16		21	

239 **Notes:**
240 JP-4 – jet propulsion fuel grade 4
241 µg/l – micrograms per liter
242 mg/l – milligrams per liter
243 B = The analyte was detected above one-half the reporting limit in an associated blank
244 J = The analyte was positively identified; the quantitation is an estimation
245 Q = One or more quality control criteria failed
246

Table 2-2   Analytical Data for ST012-W30

Sample Location:		ST012 - W30					
Sample Type: Sample Date: Parameter	Units	Baseline 7/16/2014		Post-Shut-In 9/2/2014		Post-Extraction 9/10/2014	
JP-4 (Via Petroleum Hydrocarbons)							
Diesel Range Organics [C10-C28]	mg/l	0.47	B	1.2		11	
Gasoline Range Organics [C6-C10]	µg/l	3900		13000		14000	
Total Petroleum Hydrocarbons	*mg/l*	*4.37*		*14.2*		*25*	
Volatile Organic Compounds							
1,2-Dichloroethane	µg/l	4	U	4	U	2	U
Benzene	µg/l	1200		2700		1900	
Ethylbenzene	µg/l	290		920		740	
Methylene Chloride	µg/l	8	U	12	J	4	U
m-Xylene & p-Xylene	µg/l	8	U	570		950	
Naphthalene	µg/l	32	B	110		84	
o-Xylene	µg/l	4	U	130		85	
Toluene	µg/l	4	U	160		160	
Trichloroethene	µg/l	2	U	2	U	1	U
Trichlorofluoromethane	µg/l	8	U	8	U	4	U
Xylenes, Total	µg/l	16	U	700		1000	
Total Volatile Organic Compounds	*mg/l*	*1.576*		*5.316*		*4.93*	
Other							
Bromide	mg/l	1.3		3.5	J	2.3	
Sulfate	mg/l	11		18		13	
Calcium	mg/l	240		190		200	
Chloride	mg/l	600		580		510	
Iron	mg/l	0.65		1.2		2.7	
Manganese	mg/l	2.6	Q	3.3	Q	3.2	Q
Magnesium	mg/l	52		43		43	
Sodium	mg/l	67		62		60	
Potassium	mg/l	6.7		91		55	

Notes:
JP-4 – jet propulsion fuel grade 4
µg/l – micrograms per liter
mg/l – milligrams per liter

Data Validation Flags:
B – The analyte was detected above one-half the reporting limit in an associated blank
J – The analyte was positively identified; the quantitation is an estimation
Q – One or more quality control criteria failed

247 ## 2.2.2 Microbial Data from Microbial Insights

248 Tables 2-3 and 2-4 present microbial data from Microbial Insights for the testing conducted during
249 baseline, post-shut-in, and post-extraction sampling at ST012-W11 and ST012-W30,
250 respectively. Microbial Analytical Reports are included in Appendix D.
251

Table 2-3   Microbial Data for ST012-W11

Parameter	Units	Baseline 7/16/2014 7/17/2014[1]	Post-Shut-In 9/2/2014	Post-Extraction 9/8/2014
Sample Location:		**ST012 - W11**		
Sample Type:		Baseline 7/16/2014 7/17/2014[1]	Post-Shut-In 9/2/2014	Post-Extraction 9/8/2014
qPCR				
Denitrifying Bacteria (nirK)	cells/ml	2.26E+06	4.52E+05	5.93E+05
Denitrifying Bacteria (nirS)	cells/ml	1.34E+05	1.93E+04	4.78E+04
Geobacter (GEO)	cells/ml	8.94E+01	1.53E+04	7.88E+02
Sulfate Reducing Bacteria (APS)	cells/ml	3.76E+04	6.49E+05	2.76E+06
Methanogens (MGN)	cells/ml	5.73E+05	7.00E+04	4.41E+03
PLFA				
Total Biomass	cells/ml	2.82E+04	4.39E+04	4.60E+04
Firmicutes	% of Total	34.68	20.44	0.52
Proteobacteria	% of Total	33.82	45.98	76.03
Anaerobic Metal Reducers	% of Total	1.68	1.91	0
SRB/Actinomycetes	% of Total	2.77	3.21	0.48
General	% of Total	27.06	27.09	22.42
Eukaryotes	% of Total	0	1.37	0.55
Slowed Growth		0.97	0.78	0.05
Decreased Permeability		0	0.16	0

Notes:
% - percent
ml – milliliter
PLFA – Phospholipid Fatty Acid Analysis
qPCR – Quantitative Polymerase Chain Reaction Analysis
SRB – sulfate reducing bacteria
[1]Insufficient sample volume was collected on July 16, 2014 for the full baseline sampling round, so additional sample volume was collected and submitted on July 17, 2014.

Table 2-4   Microbial Data for ST012-W30

Parameter	Units	Baseline 7/16/2014 7/17/2014[1]	Post-Shut-In 9/2/2014	Post-Extraction 9/10/2014
Sample Location:		**ST012 – W30**		
Sample Type:		Baseline 7/16/2014 7/17/2014[1]	Post-Shut-In 9/2/2014	Post-Extraction 9/10/2014
qPCR				
Denitrifying Bacteria (nirK)	cells/ml	8.06E+05	4.89E+05	3.87E+05
Denitrifying Bacteria (nirS)	cells/ml	4.25E+05	3.20E+04	1.16E+04
Geobacter spp. (GEO)	cells/ml	2.33E+01	1.06E+04	1.17E+05
Sulfate Reducing Bacteria (APS)	cells/ml	4.45E+04	4.37E+04	2.00E+05
Methanogens (MGN)	cells/ml	5.05E+04	6.42E+04	4.68E+04
PLFA				
Total Biomass	cells/ml	5.75E+04	1.02E+04	4.15E+04
Firmicutes	% of Total	48.44	24.57	14.07
Proteobacteria	% of Total	22.59	26.93	50.65
Anaerobic Metal Reducers	% of Total	5.4	1.54	1.55
SRB/Actinomycetes	% of Total	3.99	4.13	0.9
General	% of Total	19.6	32.08	30.95

Table 2-4   Microbial Data for ST012-W30

Sample Location:		ST012 – W30		
Parameter	Sample Type:	Baseline 7/16/2014 7/17/2014[1]	Post-Shut-In 9/2/2014	Post-Extraction 9/10/2014
	Units			
Eukaryotes	% of Total	0	0.75	1.89
Slowed Growth		0.9	0.75	0.25
Decreased Permeability		0.12	0	0.07

261 **Notes:**
262 % - percent
263 ml – milliliter
264 PLFA – Phospholipid Fatty Acid Analysis
265 qPCR – Quantitative Polymerase Chain Reaction Analysis
266 SRB – sulfate reducing bacteria
267 [1]Insufficient sample volume was collected on July 16, 2014 for the full baseline sampling round, so addition sample
268 volume was collected and submitted on July 17, 2014.

2.3   Solution Mixing and Injection (Injection Phase)

270 Groundwater extraction, solution mixing and injection took place on 18 July 2014 for ST012-W30
271 and on 21 July 2014 for ST012-W11. First a submersible Grundfos Redi-Flo pump was used to
272 extract 400 gallons from each of the test wells. Extracted water was stored in a 500-gallon tank.
273 The extracted water was then de-oxygenated by purging with nitrogen and mixed by placing
274 submersible pumps in the tank and recirculating the water for 30 minutes. Following
275 de-oxygenation, 12 kilograms of potassium sulfate, the terminal electron acceptor being tested,
276 and 300 grams of sodium bromide, the conservative tracer, were added to each of the tanks and
277 were thoroughly mixed. A sample from each batch of solution was collected and submitted to Test
278 America for laboratory analysis of bromide and sulfate. Table 2-5 provides the calculated
279 concentrations of bromide and sulfate compared to the laboratory results.

Table 2-5   Concentrations of Solution Used for Injection

Location	Bromide Concentration (mg/l)		Sulfate Concentration (mg/l)	
	Calculated	Lab Result	Calculated	Lab Result
ST012-W11	150	150	4,300	2,300
ST012-W30	150	220	4,300	3,800

Notes:
mg/l – milligrams per liter

282 Once the test solution was mixed, the solution was gravity fed into the associated test well. A
283 water level indicator was used to monitor groundwater levels during solution injection to make
284 sure an overflow condition did not occur.

2.4   Shut-In Period

286 Following the push phase of the field test, samples were collected twice per week from each
287 monitoring well using low-flow procedures and were sent to Test America for bromide and sulfate
288 analysis. Additionally, readings were collected from the bromide meters to provide instantaneous
289 data to enable decision making with regards to how long to wait prior to conducting the pull-phase

290 of the test. The data from the bromide probes, however, were deemed unreliable early on in the
291 shut-in period. The bromide probes were removed from the wells, re-calibrated, and replaced
292 inside the wells, but the data continued to be unreliable. On 16 August 2014, the bromide probes
293 were removed from the wells and sent back to the supplier. Given that the bromide probes could
294 not be used, the bi-weekly sample results were compiled, and trend graphs were created and
295 updated as soon as data became available so that decisions could be made on when to conduct
296 the pull phase.
297
298 As indicated in the EBR Field Test Plan, it was anticipated that the shut-in period would last
299 between two and four weeks. The actual duration was dependent on how long it would take for
300 the conservative tracer, bromide, to reach ambient conditions. The shut-in period would last no
301 more than twice the duration that it took to reach ambient conditions. Based on laboratory data
302 through 19 August 2014, approximately four weeks into the shut-in period, with concentrations
303 approaching baseline conditions (Table 2-6), a decision was made to schedule the extraction
304 phase for the week of 1 September 2014.
305

Table 2-6   Bromide and Sulfate Concentrations during Shut-In Period

Sample Type	Date	ST012–W11		ST012–W30	
		Bromide (mg/l)	Sulfate (mg/l)	Bromide (mg/l)	Sulfate (mg/l)
Baseline	7/16/2012	1.6	5.4	1.3	11
Shut-in	7/22/2014	55	1,000	99	1,900
Shut-in	7/24/2014	39	2,000	92	1,600
Shut-in	7/29/2014	18	940	47	840
Shut-in	7/31/2014	12	610	35	660
Shut-in	8/5/2014	6.2	300	20	320
Shut-in	8/7/2014	4.9	230	16	240
Shut-in	8/12/2014	3.0	110	11	140
Shut-in	8/15/2014	2.4	73	8.7	100
Shut-in	8/19/2014	1.9	42	6.5	67
Shut-in	8/21/2014	1.8	31	5.2	49
Shut-in	8/26/2014	1.6	18	4.5	34
Shut-in	8/29/2014	1.5	14	3.9	24
Post-Shut-In	9/2/2014	2.6	6.4	3.5 J	18

Notes:
mg/l – milligrams per liter
J = The analyte was positively identified; the quantitation is an estimation

306
307 Prior to conducting extraction, low flow samples were collected from each monitoring well, and
308 were submitted to Test America and Microbial Insights to be tested for the full suite of analysis
309 that was conducted during baseline sampling. The results of these samples are presented in
310 Tables 2-1 through 2-4 and discussed in Section 3.

311 **2.5   Extraction Phase**

312 For the extraction phase of the field test, a submersible Grundfos Redi-Flo pump was installed
313 sequentially in ST012-W11 and ST012-W30 at 248 and 216 feet below top of casing, respectively.

314   The pump extracted groundwater at a rate of up to 20 gallons per minute (gpm) to extract as much
315   of the solution that was introduced to the groundwater as possible.
316
317   Extraction started at ST012-W11 on 4 September 2014. 1,000 gallons of water were extracted
318   from ST012-W11 on 4 September 2014 and 9,000 gallons were extracted during a continuous
319   period from 6 September through 7 September 2014. A pumping rate of 5 to 6 gpm was
320   maintained during extraction. Extracted water was pumped into a 21,000-gallon frac tank and a
321   slip line from the main conveyance line was used to collect a sample at intervals of approximately
322   500 gallons. The collected samples were shipped to Test America for bromide and sulfate
323   analysis. Bromide and Sulfate results during the pull phase in ST012-W11 are tabulated in
324   Table 2-7.
325

Table 2-7   Bromide and Sulfate Concentrations for ST012-W11 during Extraction Phase

Date / Time	Quantity Pumped (gallons)	Bromide (mg/l)	Sulfate (mg/l)	Date / Time	Quantity Pumped (gallons)	Bromide (mg/l)	Sulfate (mg/l)
9/4/14 15:05	500	2.9	260	9/7/14 9:57	5,500	2.60	280
9/4/14 16:41	1,000	2.8	260	9/7/14 11:29	6,000	2.50	280
9/6/14 21:47	1,674	2.6	320	9/7/2014 13:43	6,500	2.50	280
9/6/14 22:48	2,004	2.6	260	9/7/2014 15:25	7,000	2.50	280
9/7/14 0:23	2,500	2.6	270	9/7/2014 17:00	7,500	2.50	280
9/7/14 1:55	3,000	2.6	270	9/7/2014 18:33	8,000	2.80	290
9/7/14 3:30	3,500	2.6	270	9/7/2014 20:18	8,500	2.70	280
9/7/14 5:03	4,000	2.6	280	9/7/2014 21:54	9,000	2.70	280
9/7/14 6:35	4,500	2.6	280	9/7/2014 23:33	9,500	2.70	280
9/7/14 8:26	5,000	2.6	280	9/8/14 01:10	10,000	2.70	280

Notes:
mg/l – milligrams per liter.

326
327   Initial results from Test America for the pull-phase of ST012-W11 were used to calculate the total
328   amount of sulfate that was extracted from the groundwater. The results of this calculation
329   indicated that more sulfate was extracted from the groundwater than was introduced during the
330   push-phase of the field test. A request was made that the laboratory re-analyze a select number
331   of samples, and the reported results were confirmed. During re-analysis, Amec Foster Wheeler
332   determined that the high sulfate concentrations reported by the laboratory were within range of
333   background concentrations at the site.
334

335 On 7 September 2014, groundwater extraction began at ST012-W30 using the same techniques
336 as at ST012-W11. Extraction of the first 500 gallons removed from this well occurred over a
337 14-hour period. Pumping rates from this well could not be sustained at a constant rate and
338 required personnel to toggle the pump on and off. Due to the low yield of the well, the target
339 volume of water to be extracted during the pull-phase was reduced to 1,000 gallons. During
340 extraction of the remaining 500 gallons of water to be pumped from the well, three rounds of
341 samples were collected. Extraction of this volume of water occurred over an approximate 25-hour
342 period. The collected samples were shipped to Test America for bromide and sulfate analysis.
343 Bromide and Sulfate results for samples collected during the pull phase in ST012-W30 are
344 tabulated in Table 2-8. Historical groundwater monitoring upgradient of site contamination has
345 shown background sulfate concentrations generally range from 250 to 300 milligrams per liter
346 (mg/l) (BEM,1998) Sulfate concentrations in ST012-W30 below typical background
347 concentrations indicate potential LNAPL-influenced conditions.
348

**Table 2-8   Bromide and Sulfate Concentrations for ST012-W30
during Extraction Phase**

Date / Time	Quantity Pumped (gallons)	Bromide (mg/l)	Sulfate (mg/l)
9/7/14 6:05	500	2.7	18
9/9/14 8:03	500	2.3	15
9/9/14 10:49	667	2.6	15
9/9/14 13:45	834	2.6	19
9/10/14 10:56	1,000	2.4	16

Notes:
mg/l – milligrams per liter

349 ## 2.6   Post-Extraction Sampling

350 At the conclusion of the extraction phase for each well, post-extraction samples were collected
351 and submitted to Test America and Microbial Insights to be tested for the full suite of analysis that
352 was conducted during baseline sampling. The results of these samples are presented in
353 Tables 2-1 through 2-4 and discussed in Section 3.

354 ## 2.7   Waste Management

355 The groundwater purged for low flow sampling during the shut-in period and the water purged
356 from the test wells during the pull phase of the EBR field tests were contained in a single 21,000
357 gallon frac tank. The groundwater was treated in the SEE groundwater treatment system.

358 ## 2.8   Deviations from the Work Plan

359 Based on unforeseen conditions, the following deviations from the work plan were implemented:

360   1. The in-line bio-flo™ filters were not used to collect samples for microbial analysis because
361   they clogged before the required amount of water was collected. Microbial Insights
362   indicated that this situation occurs frequently and that collecting bottles of water that the
363   lab will process through a filter prior to testing provides the same level of confidence with
364   the data. Therefore, this is not a significant deviation.

365   2. The in-situ bromide probes did not provide reliable data and were removed from the wells
366   within the early stages of the shut-in period. Amec Foster Wheeler relied upon laboratory
367   data to make field decisions during the shut-in period, which required a few additional days
368   for results to be available; trend predictions were used to schedule a time to conduct the
369   extraction phase. Based on the results of laboratory testing, the extraction phase was
370   conducted within the appropriate timeframe; therefore, the suspension of the use of the
371   in-situ bromide probes is not considered a significant deviation from the work plan.

372   3. Due to the slow extraction rates achievable from ST012-W30, only 1,000 gallons of water
373   was removed during the extraction phase compared to the 10,000 gallons targeted in the
374   EBR Field Test Plan. This may be due to fouling of the well over time. Well fouling limits
375   evaluation of hydraulic conductivity for the well. Extraction of a smaller volume of water
376   than planned results in only partial extraction of the injected fluids. This limits evaluation
377   of degradation kinetics; however, data from the shut-in phase is available for calculation
378   of kinetic parameters.

379 ## 3.0   EVALUATION OF RESULTS AND RECOMMENDATIONS

380 Evaluation of the analytical data obtained during the EBR Field Test and estimation of hydraulic
381 and biological degradation parameters are presented in this section.

382 ### 3.1   Evaluation of Laboratory Analytical Results

383 Analytical concentration data for ST012-W11 presented in Table 2-1 show no significant change
384 between the baseline and the post-shut-in period for most of the analytes evaluated. However,
385 there is a decrease in total TPH and total VOC concentrations observed between these monitoring
386 periods and the post-extraction sampling round. Additionally, sulfate, calcium and chloride
387 concentrations for the post-shut-in period increased as well. These conditions were not expected
388 and are interpreted to be a result of cleaner/background groundwater within part of the screened
389 interval being drawn into the well rather than pulling only injected water back into the well.
390 Historical groundwater monitoring upgradient of site contamination has shown background sulfate
391 concentrations generally range from 250 to 300 mg/l (BEM,1998) which is similar to the
392 concentrations observed in ST012-W11 during the pull phase.
393
394 Results for ST012-W30 presented in Table 2-2 indicate an increase in concentration for total TPH
395 and total VOCs in both the post-shut-in sample and post-extraction sample in comparison with
396 the baseline sample results.

397 ### 3.2   Evaluation of Microbial Analytical Results

398 Microbial results for samples collected from ST012-W11 (Table 2-3) show an increase in the
399 quantity of sulfate reducing bacteria between the baseline and post-shut-in sampling events.
400 Another increase in these bacteria was observed during the post-extraction sampling event, for
401 an overall increase in density of two orders of magnitude. Geobacter (which is implicated in
402 biological metals reduction) increased by three orders of magnitude between baseline and
403 post-shut-in sampling rounds and then decreased by two orders of magnitude during the
404 post-extraction sampling event. Methanogenic bacterial densities decreased by two orders of
405 magnitude between the baseline and post-extraction sampling events.
406
407 Although increases in total biomass were modest over the course of the test, the percentages of
408 Firmicutes and Proteobacteria were approximately equal during baseline sampling and shifted
409 such that Proteobacteria was more prevalent in the post-shut-in sample and even more prevalent
410 in the post-extraction sample. An increase in the proportion of Proteobacteria present coupled
411 with an increase in biomass suggests metabolism of a readily available growth substrate. The
412 decline in Firmicutes suggests a transition to a more aerobic environment over the course of the
413 test and/or the extraction of more oxygenated water from upgradient of contamination (see
414 Section 3.1).
415
416 Microbial results for samples collected from ST012-W30 (Table 2-4) show no change in sulfate
417 reducing bacteria between the baseline and post-shut-in sampling events; however, the density
418 of these organisms increased by an order of magnitude between the post-shut-in and the
419 post-extraction sampling events. Geobacter densities increased by three orders of magnitude
420 between baseline and post-shut-in sampling rounds and increased by another order of magnitude
421 during the post-extraction sampling event. Methanogenic bacterial densities decreased by two
422 orders of magnitude between the baseline and post-extraction sampling events.

423 The percentage of Firmicutes was higher than the percentage of Proteobacteria in the baseline
424 sample but shifted such that percentages of these groups were relatively the same in the
425 post-shut-in sample; Proteobacteria were more prevalent in the post-extraction sample.

426 ## 3.3   Estimation of Hydraulic Parameters

427 Water elevations from transducer data collected throughout the field test were evaluated for
428 estimation of hydraulic parameters. However, groundwater elevation data from the transducers
429 generally showed rapid and abrupt changes during the pull phases which was likely related to
430 fouling of the well screens; this limited analysis of pull phase data for estimation of hydraulic
431 conductivity. Transducer data was not recorded for the ST012-W11 push phase so only
432 groundwater elevation data collected during the push phase in ST012-W30 provides potentially
433 useable data. The push phase in ST012-W30 was analyzed using the groundwater model from
434 the RD/RAWP. The purpose was to calibrate the model to the observed elevation increases
435 associated with the ST012-W30 push phase by varying the hydraulic conductivity. The
436 push-phase liquid injection was modeled and the predicted groundwater elevations were
437 compared to the observed elevations from the transducer. Unfortunately, the groundwater
438 elevation data corresponding to the push phase included about four elevation spikes related to
439 increases in solution addition rates (see Graph 3-1) and the model could not be effectively
440 calibrated to this data. Therefore, no refinement to the model hydraulic conductivity values are
441 recommended based on EBR Field Test results.

442 ### Graph 3-1   ST012-W30 Injection-Phase Elevations

443
444 **Notes:**
445 ft msl – feet above mean sea level
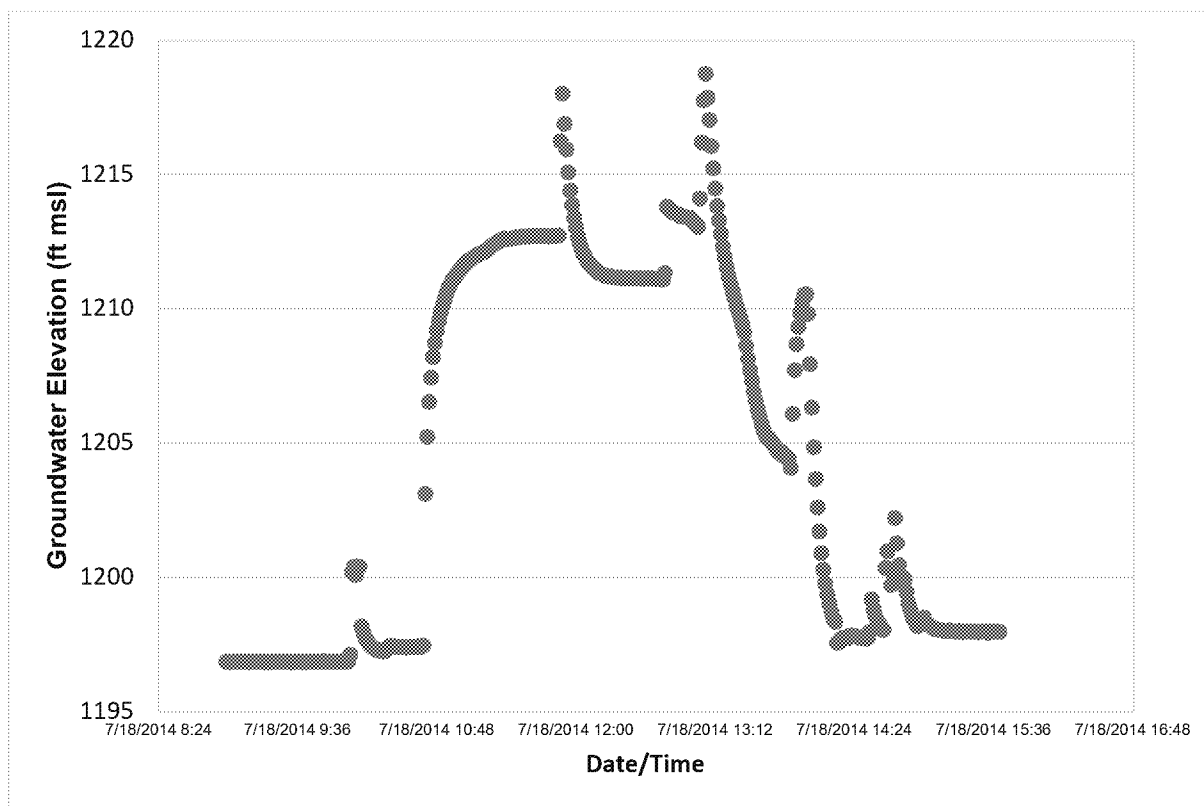
446   A similar approach was used to evaluate dispersivity at ST012 by varying dispersivity in the
447   groundwater model to generate predicted bromide concentrations over time that compare well to
448   the laboratory analytical results for bromide. The groundwater model uses a single set of
449   longitudinal, horizontal, and vertical dispersivities throughout the model domain so the objective
450   was to obtain the best calibration to both the ST012-W11 and ST012-W30 data with the same
451   dispersivity values. Table 3-1 shows the dispersivity values for the six calibration runs and
452   Graphs 3-2 and 3-3 show the calibration model run predicted bromide results compared to the
453   analytical data. The shape of the bromide curve for ST012-W30 is closer to what is predicted by
454   typical ratios of longitudinal, horizontal, and vertical dispersivities so the calibration runs focused
455   on matching that data.

Table 3-1   Dispersivity Values Used in Groundwater Model Calibrations

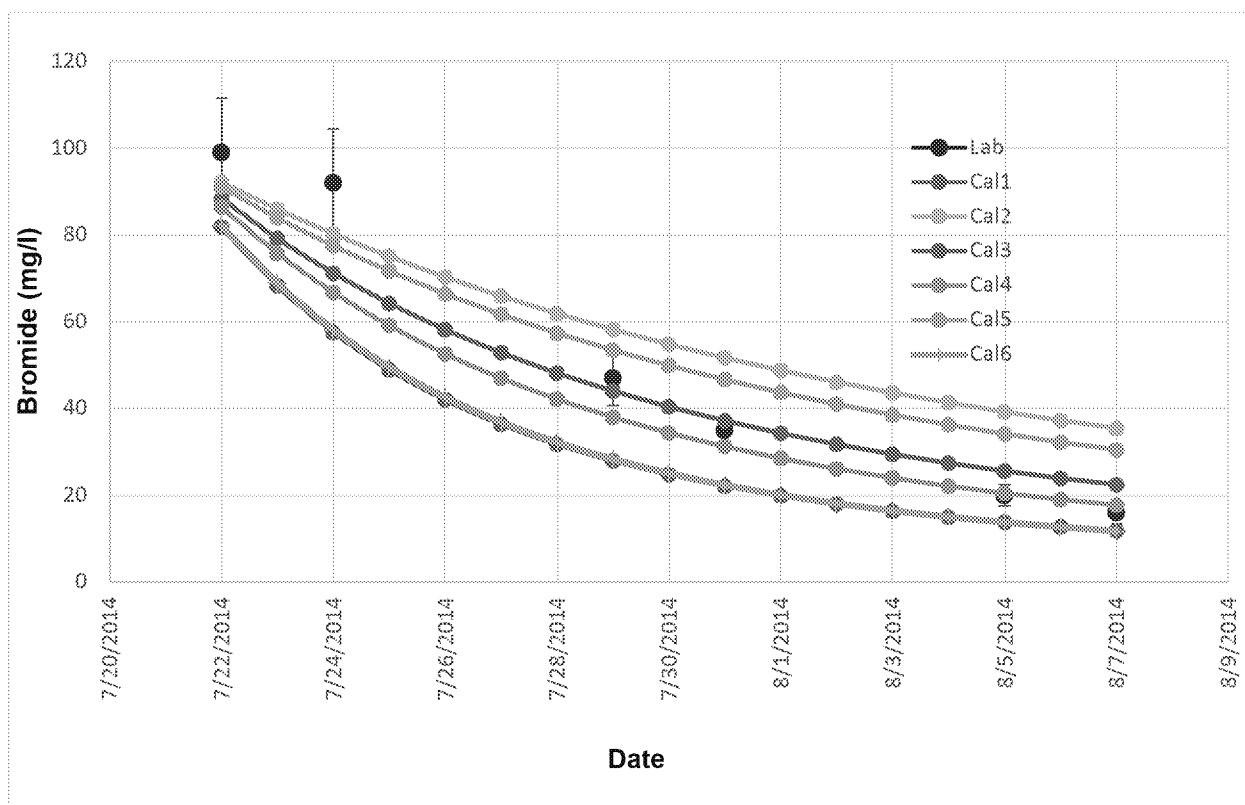| Calibration Run	Longitudinal	Horizontal	Vertical
1	19	1.9	0.19
2	9.5	0.95	0.095
3	38	3.8	0.38
4	20	6.66	1
5	10	3.33	0.5
6	30	10	3

456

Graph 3-2   ST012-W11 Dispersivity Calibration Runs

457
458   **Notes:**
459   mg/l – milligrams per liter
460
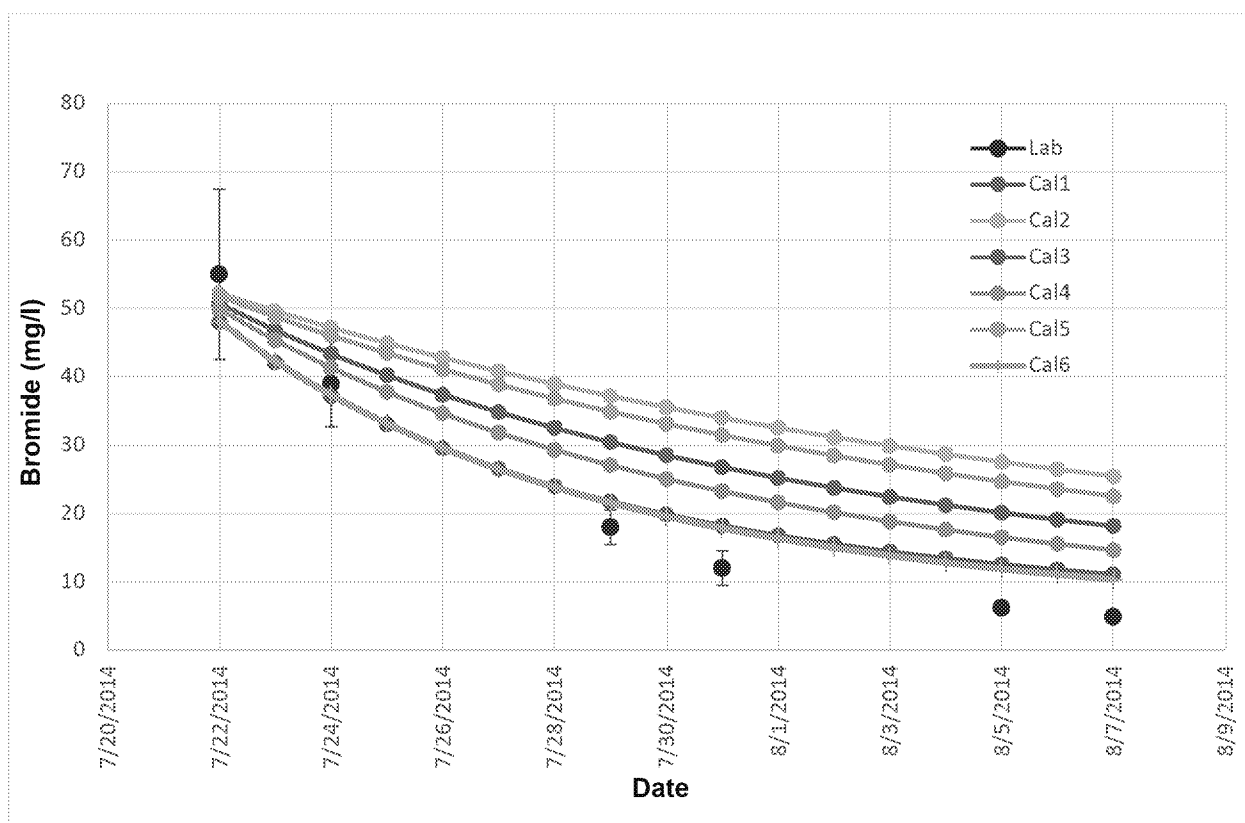
461 **Graph 3-3   ST012-W30 Dispersivity Calibration Runs**

462
463 **Notes:**
464 mg/l – milligrams per liter
465

466 Based on this analysis, the recommended dispersivity values for future EBR modeling are from
467 Calibration Run 4 (20, 6.66, and 1). These compare to values of 10, 1, and 0.1 used in previous
468 RD/RAWP modeling for the LSZ. As can be seen by comparing the curves for Calibration Run 4
469 to Calibration Run 2 (which uses dispersivity values close to the RD/RAWP model), use of
470 Calibration Run 4 values will predict lower contaminant concentrations with time than previous
471 modeling.

472 ## 3.4   Estimation of Sulfate Utilization Rate

473 Sulfate utilization has been estimated from the shut-in period of ST012-W11 and ST012-W30.
474 Well fouling in ST012-W30 limited the extraction volume during the extraction-phase of the test.
475 The limited volume extracted did not provide a sufficient data set to estimate sulfate utilization
476 during the pull phase. As discussed in Section 3.1, the increasing sulfate concentrations in
477 ST012-W11 during the pull phase of the test indicate that background groundwater sulfate
478 concentrations were being pulled into the well and prevent the accurate estimation of sulfate
479 utilization during the pull phase.
480
481 Instead, sulfate utilization was estimated from sulfate concentration collected during the shut-in
482 period. Graph 3-4 shows normalized concentrations of bromide and sulfate (measured
483 concentration divided by initial calculated concentration) for ST012-W11 during the shut-in period.
484 The normalized sulfate concentration is higher than the normalized bromide concentration for the
485 majority of the shut-in period; however, after the initial 24 July 2014 sample, sulfate decreased

486 faster than bromide and the data after this date are useful for evaluating the sulfate utilization
487 rate.

488 **Graph 3-4   ST012-W11 Shut-In Phase Bromide and Sulfate**
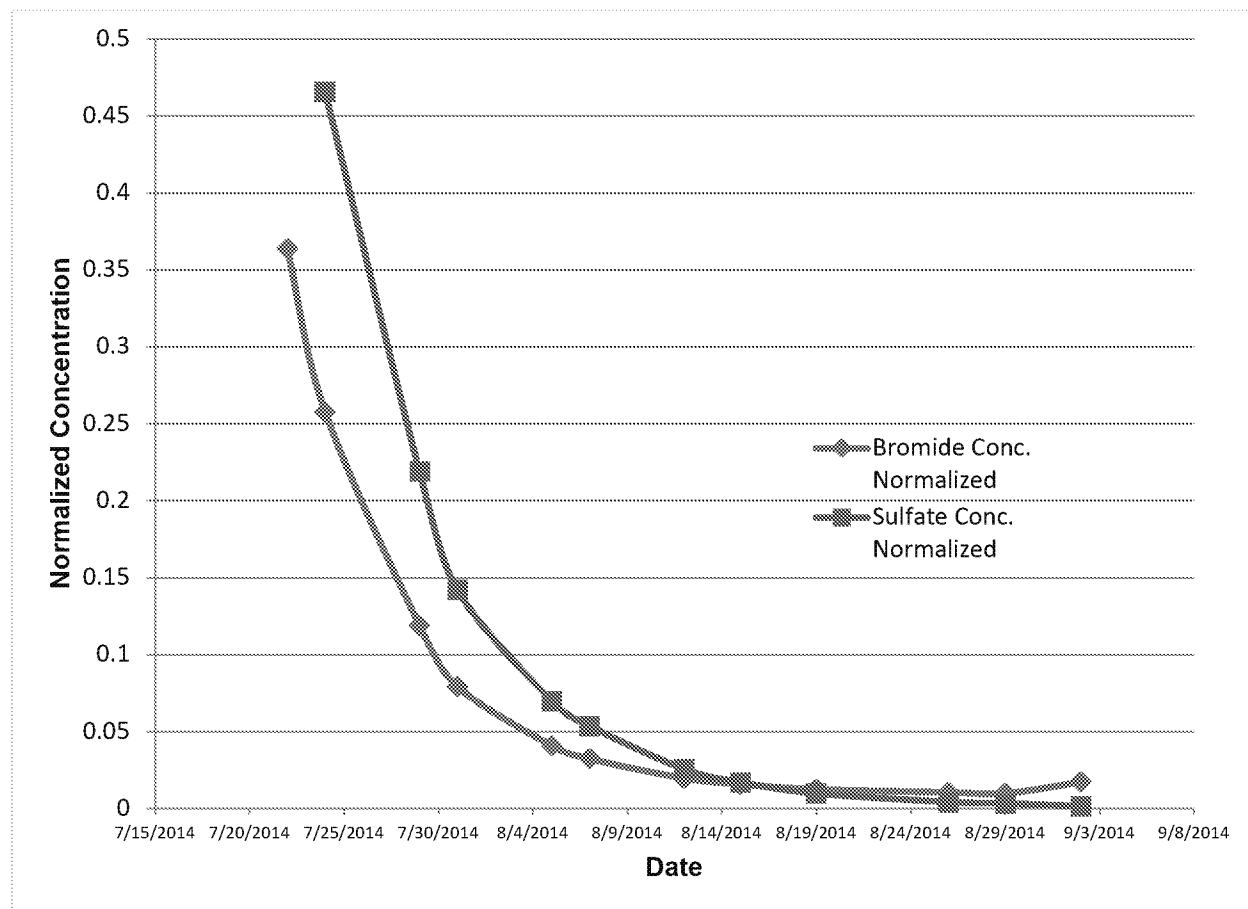
489
490
491 The data collected during the shut-in period for ST012-W30 also provides a useful data set for
492 estimation of the sulfate utilization rate. Graph 3-5 shows the normalized concentrations for
493 ST012-W30. Normalized sulfate concentrations are lower than normalized bromide
494 concentrations throughout the shut-in period which is expected where sulfate is being consumed.
495 Using the data from the ST012-W11 and ST012-W30 shut-in periods, a Lineweaver-Burk analysis
496 was performed. In this analysis, the half saturation coefficient and the maximum substrate
497 utilization rate were estimated from a graph of the inverse utilization rate and the inverse sulfate
498 concentration. Using this method (see calculations in Appendix E), the maximum sulfate utilization
499 rate ranges from 33 to 75 mg/L-day for ST012-W11 and ST012-W30, respectively. The half
500 saturation coefficient, which represents the sulfate concentration at which reaction rate is ½ of
501 the maximum rate, ranges from 4,100 to 4,200 mg/l of sulfate for ST012-W30 and ST012-W11
502 respectively.
503
504 These kinetic values were then used to model the sulfate consumption and TPH degradation
505 using Monod-type kinetics. Initial sulfate and TPH concentrations used in the model were selected
506 to represent background influx and LNAPL influenced conditions, respectively. A first-order
507 degradation curve was fitted to these modeled values to graphically approximate a first-order
508 maximum TPH degradation rate with a coefficient of 0.03 day^{-1} (see Appendix E). This value

509 compares to a value of 0.0125 day^{-1} for the maximum utilization rate of hydrocarbons other than
510 benzene in the RD/RAWP modeling indicating that the maximum degradation rate under sulfate
511 reducing conditions in the EBR field test was approximately 2.4 times greater than previously
512 modeled. First order kinetics are a reasonable representation of Monod degradation kinetics when
513 the sulfate concentration is much less than the half saturation coefficient. This is the case for
514 background sulfate concentrations; therefore, the RD/RAWP model is based on reasonable but
515 conservative kinetic values. Future updates to the model should incorporate the estimated
516 Monod-type kinetic values to evaluate TPH degradation rates for sulfate concentrations
517 approaching and greater than the half saturation coefficient.

518 **Graph 3-5   ST012-W30 Shut-In Phase Bromide and Sulfate**

519
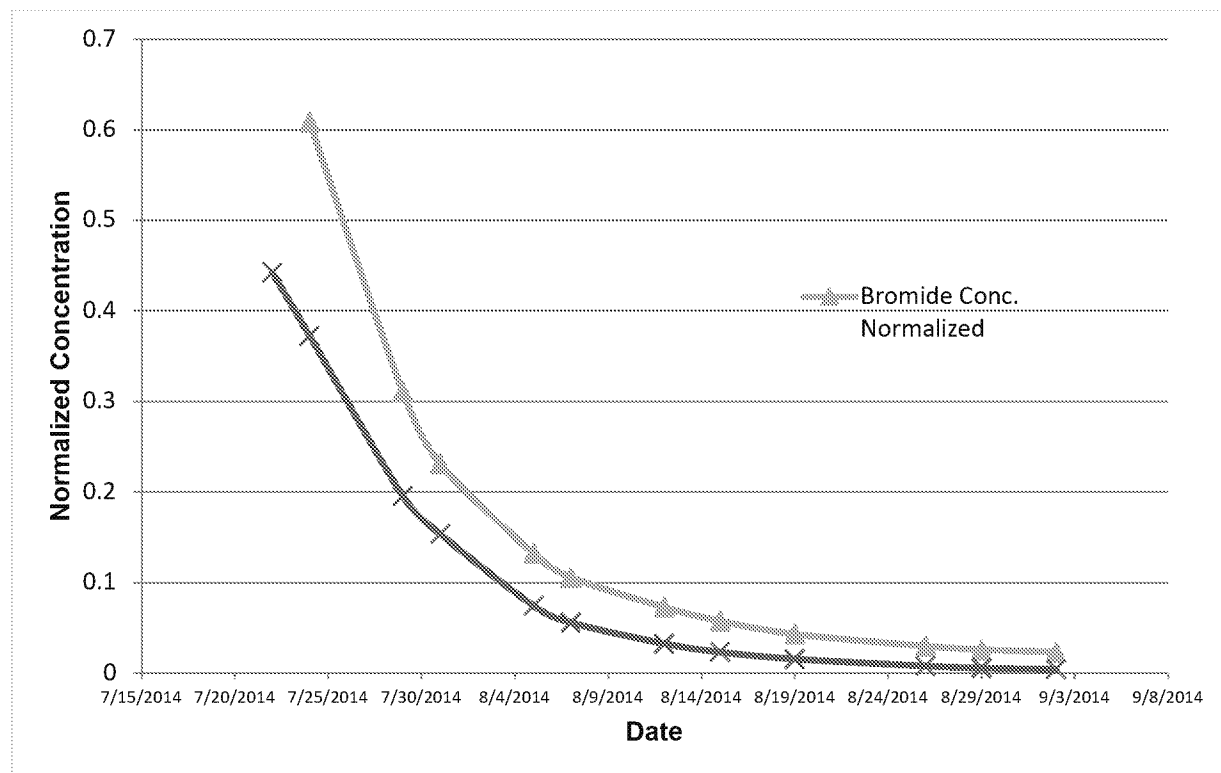
3.5   Recommendations

521 The data collected for sulfate degradation from the EBR Field Test indicates that sulfate degrading
522 bacteria populations increased and that dispersivity values and sulfate utilization rates were more
523 favorable than the assumed values used in the RD/RAWP EBR modeling. These findings, in
524 combination with previous studies that concluded sulfate reduction was the dominant naturally
525 occurring process for contaminant assimilation (BEM, 1998), indicate that sulfate amendment
526 should be included in the EBR strategy. Sulfate amendment could either be used solely or in
527 combination with aerobic methods to achieve remediation goals.
528
529 The next step will be to develop a refined EBR approach using the new parameters developed in
530 this study and to prepare an RD/RAWP addendum to document the revised approach and
531 implementation strategy.

4.0 REFERENCES
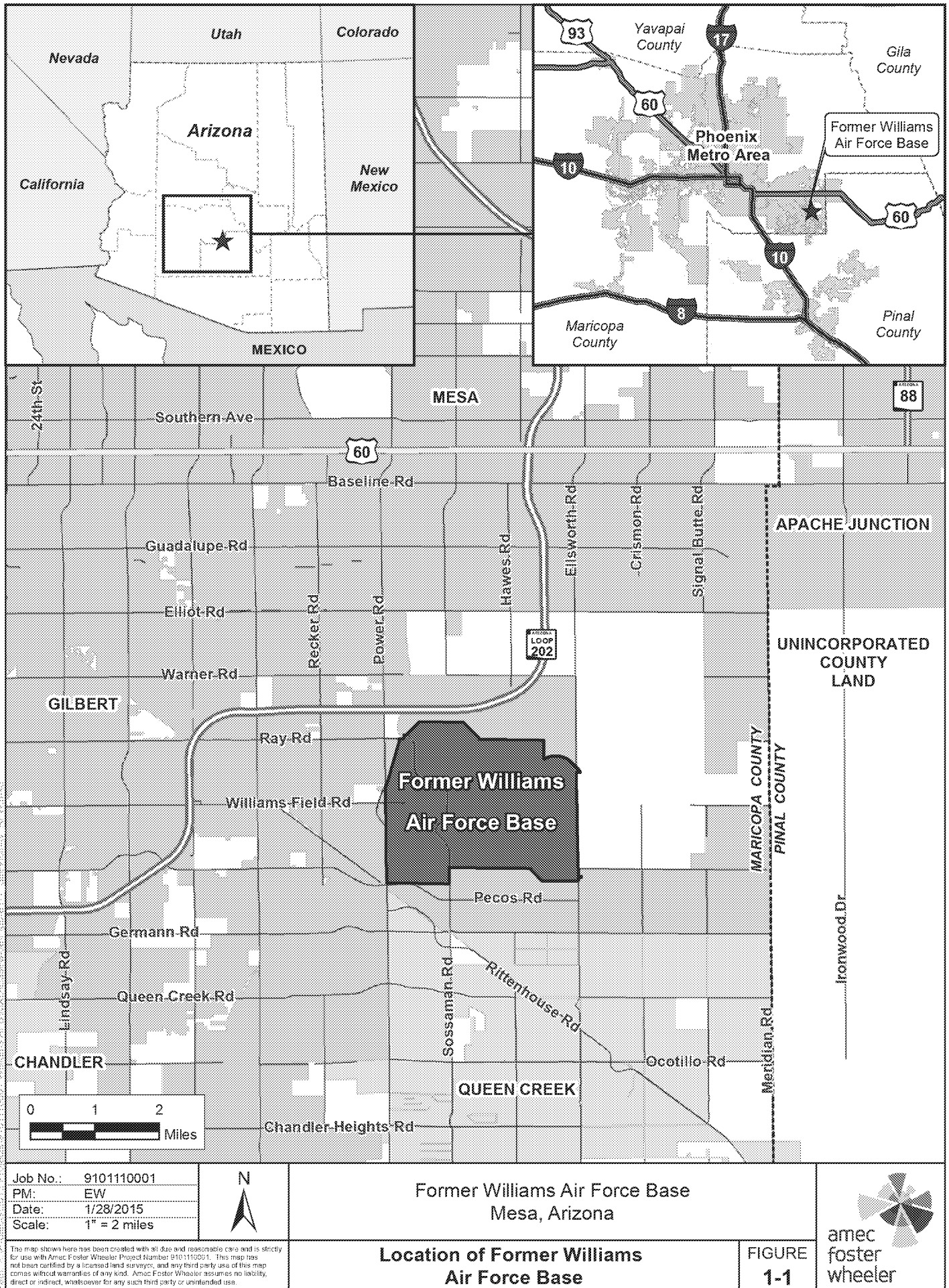
Air Force Civil Engineer Center (AFCEC), 2013. *Record of Decision Amendment 2, Groundwater, Operable Unit 2 (OU-2), Site ST012, Former Williams Air Force Base, Mesa, Arizona.* 28 September 2013. [AR#1633]

AMEC Environment & Infrastructure, Inc. (AMEC), 2014a. *Final Remedial Design and Remedial Action work Plan for Operable Unit 2, Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona.* 20 May 2014 [AR#301162].

AMEC, 2014b. *Final Uniform Federal Policy Quality Assurance Project Plan (Enhanced Bioremediation Field Test Plan), Operable Unit 2, Site ST012, Liquid Fuels Storage Area, Former Williams Air Force Base, Mesa, Arizona.* 20 May 2014 [AR#421651].

BEM, 1998. *Final Consolidated Treatability Study Report (TSR) Liquid Fuel Storage Area (Site ST-12), Williams AFB, Arizona.* September 1998 [AR#947].

FIGURES
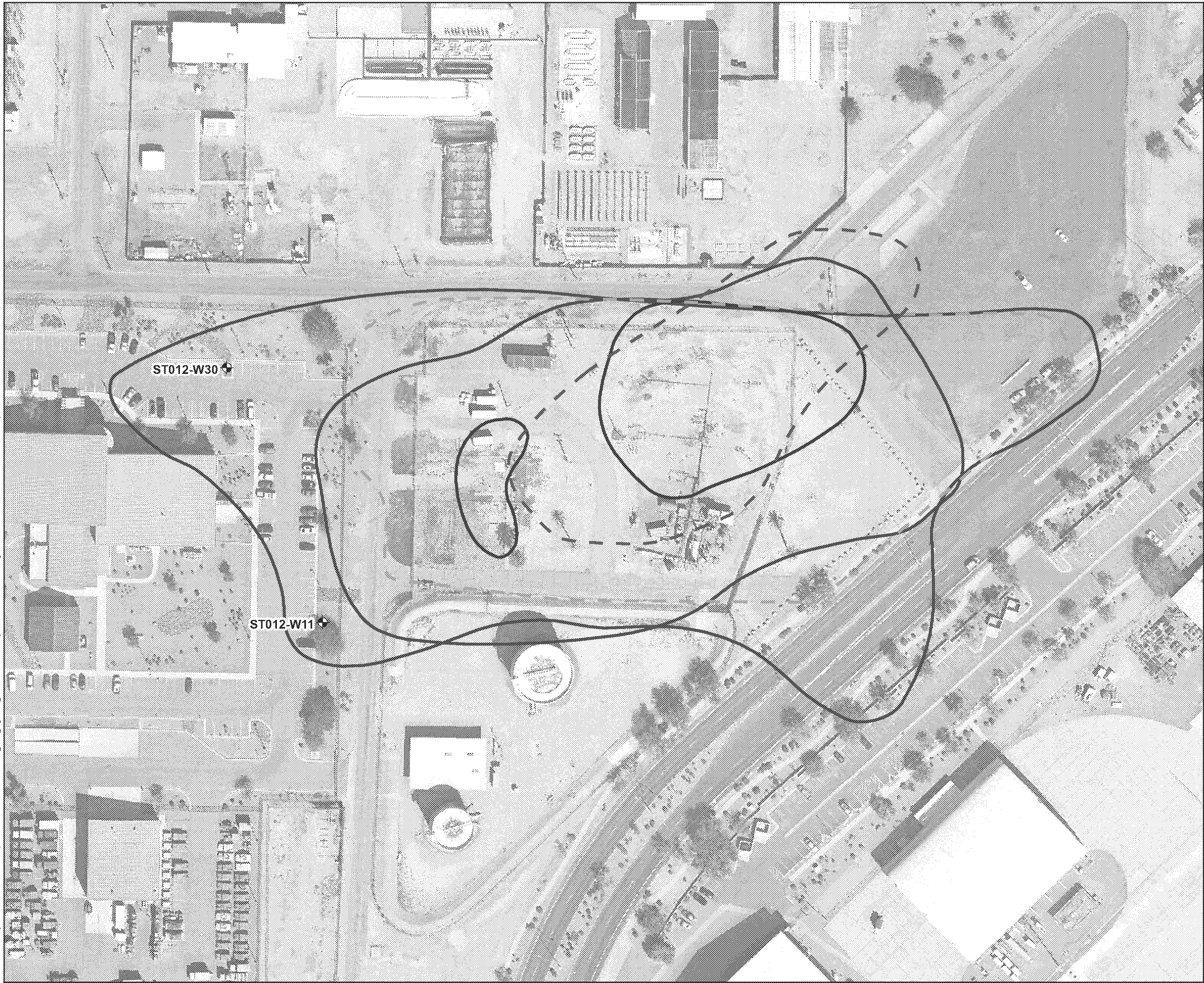
Former Williams Air Force Base
Mesa, Arizona

Location of Former Williams Air Force Base

Job No.:	9101110001
PM:	EW
Date:	1/28/2015
Scale:	1" = 2 miles

FIGURE
1-1

amec
foster
wheeler

ED_005025_00020260-00026

Legend

- Site ST012
- Former Williams AFB Boundary

0   0.25   0.5   1
Miles

Job No.:	9101110001
PM:	EW
Date:	2/4/2015
Scale:	1" = 0.5 mile

N

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Former Williams Air Force Base
Mesa, Arizona

ST012 Site Location Map

FIGURE
1-2

amec
foster
wheeler

Legend

◆ Push-Pull Test Well
— CZ RD/RAWP LNAPL extent
— UWBZ RD/RAWP LNAPL extent
···· LSZ RD/RAWP LNAPL extent
– – LSZ SEE Treatment Zone
— - CZ/UWBZ SEE Treatment Zone

ST012-W30 ◆

ST012-W11 ◆

Notes: SEE - Steam Enhanced Extraction
CZ - Cobble Zone
LSZ - Lower Saturated Zone
UWBZ - Upper Water Bearing Zone
LNAPL - Light Non-Aqueous Phase Liquid
EBR - Enhanced Bioremediation
RD/RAWP - Remedial Design/Remedial
Action Work Plan

0   50   100
═══════ Feet

N

Draft
Enhanced Bioremediation Field Test Report
Former Williams Air Force Base
Mesa, Arizona

EBR FIELD TEST LOCATIONS	FIGURE 1-3

Job No.
PM: 9101110001
Date: 4/22/2015
Scale: 1" = 100 feet

amec
foster
wheeler

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APPENDIX A

SAMPLE COLLECTION RECORDS